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REVIEW OF THE SHIELDING REQUIREMENT OF THE E-497 TARGET MAGNET

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This note is a review of the shielding requirements of the E-497 target maget. Several quantities of interest were reviewed including external dose rate, activation of the cooling water, and soil activation. Effectiveness as a critical device is <u>not</u> considered here.

This target magnet design was studied using code CASIM[1)] which uses a Monte Carlo technique to calculate the quantities of interest here. The principal uncertainty in such a calculation is the selection of a cylindrically symmetric geometry (for maximum computational efficiency) which is an accurate approximation of the actual geometry at hand. In this particular case 3 different runs of the code were made as follows:

Case A: The dimensions of the target magnet were taken radially to be those which would yield cross sectional areas equal to those of the actual rectangular geometrics.[2)] In this case, the coils and their lead shielding is included in order to estimate the activation of the cooling water.

Case B: The actual radial dimensions of the target magnet measured vertically above the beam channel were used in order to obtain dose rates external to the target box, particularly important in outdoor areas above the target magnet.

Case C: Dimensions equal to Case B were used except that the layer of polyethylene placed underneath the dump is included.

In all 3 cases, the horizontal bend of the beam is not taken into account. This will make an insignificant difference in the quantities considered by this TM but of course has consequences with respect to dose rates in the downstream area and in the experimental hall, since the secondary beam pathway provides a leakage path. In all cases a 400 GeV incident proton beam focused in a spot 2.5 mm square is assumed to be incident on a 17cm long iron target. The aluminum coils were treated as aluminum with its density reduced to compensate for the water in the coils. The brass sleeve surrounding the beam channel was considered to be iron in the calculation because only 5 different materials are allowed by the present version of the code. Figures 1, 2 and 3, show contour plots of equal star density for each of the 3 cases superimposed upon the appropriate geometrical layout used as input to the code. In these figures concrete is assumed to surround the target magnet with infinite radial extent. One can thus determine quantities of interest at the boundary of any radius of proposed shielding.

1. External Dose Equivalent Rate.

The proposal is to operate this target magnet at intensities as high as 1×10^{12} protons/pulse at an energy of 400 GeV. A plausible quantity of concrete shielding on top of the target magnet would be 7.5 feet.

The results were that Case A gives a maximum star density of 2×10^{-11} stars/cm^3·proton while Case B gives a maximum of 2×10^{-11} stars/cm^3·proton since we are outside a thick shield, the conversion from star density to dose is 9×10^{-6} rem/star/cm^3. [2] At 10^{12} protons/pulse, 10 second cycle time we thus have external to such shielding 360 pulse/hr x 1×10^{12} protons/pulse x 2×10^{-11} stars/(cm^3 proton) x 9×10^{-3} mrem cm^{-3}/star = 64 mrem/hr in the worst spot. Three feet of concrete will give a factor of 8 attenuation in such a place so that the worst spots could easily be shielded further to be below 10 mrem/hr. The area downstream of the target magnet should be shielded by approximately 10 feet of concrete to achieve the same dose rates again not considering the target magnet as a critical device of the cooling water.

2. Activation of the cooling water.

The calculation yields a production of 2.4 stars/proton in the coil region. When running at 1×10^{12} protons/pulse, 10 second cycle time, this implies 8.6×10^{14} stars/hr or 4.32×10^{18} stars/yr. In order to calculate the activation of the water it is efficient to employ an indirect technique which relies on the fact that aluminum will yield nearly the same amount of ^{22}Na atoms (2.6 yr halflife) per star as will soil. Using the conversion factor of 0.02 atoms of ^{22}Na per star in soil, [3] this implies a production of 8.64×10^{16} atoms comparable to that for ^3H. The inverse ratio of halflives of ^{11}C to ^3H is 3.2×10^5 which is also the ratio of the concentrations of the 2 radionuclides at saturation. Thus a large quantity of ^{11}C builds up in the water and releases of such water (in an open loop, for example) can present dose rate problems. The areas near the cooling towers will have to be monitored for high dose rates.

3. Soil Activation.

The soil activation is best estimated in parallel with P.J. Gollon's work on the antiproton target area, reported in Ref. 3. For the case at hand it is necessary to separately determine the star production in the unprotected soil in the 3 regions considered here. Any star produced outside of the 7.5 feet of concrete shielding assumed above is assumed to participate in the soil activation. A one foot thick concrete floor is assumed underneath the target box: The total star production in each region is:

Case A: 2×16^{-3} stars/proton (both sides)

Case B: 2.7×10^{-4}stars/proton

Case C: 1.31×10^{-2} stars proton

Total: 1.54×10^{-2} stars proton

Thus at 10^{12} protons/pulse, 10 sec cycle time, and 5000 hr/year running we have: 2.8×10^{16} stars/year.

In Ref. 3 it was found that 2.5×10^{17} stars/yr yields 100% of the EPA concentration limits for ^3H and ^{22}Na using a conservative method of estimating dilution factors in the aquifer. The P Center beam elevation is approximately 733 ft as compared with the 727 ft for the antiproton target, thus implying a longer path (and hence more decay) to the aquifer.

of ^{22}Na in the aluminum per year or 19.4 mCi of activity at saturation. This quantity of ^{22}Na is produced in a mass of approximately 2.56×10^6 grams of aluminum thus yielding an average concentration at saturation of 7.6 nCi/g of ^{22}Na in the coils. S.I. Baker has data comparing the activation of soil and water exposed to the same incident hadron flux in the Neutrino Target tube during a 2 month period[4] results were that 0.16 nCi/gram of ^{22}Na in Aluminum implies 0.135 nCi/mℓ of ^{3}H (12.33 yr. halflife) in the water and 0.88 nCi/mℓ of ^{7}Be (53 day halflife) in the water. Thus in the coils, if there are no leaks followed by refills, one builds up during such a 2 month period, correcting for decay, a concentration of 0.33 nCi/gm of ^{22}Na in the aluminum with consequent concentrations of 0.277 nCi/mℓ of ^{3}H and 1.82 nCi/mℓ of ^{7}Be in the cooling water. A year of such running would raise the concentrations in the water to 1.61 nCi/mℓ of ^{3}H and 3.33 nCi/mℓ of ^{7}Be. The saturation concentrations of ^{3}H could be 28.8 nCi/mℓ but would require approximately a decade of such running to approach these levels.

The volume of water in the coils is approximately 2.28×10^5 mℓ or about 60 gal. while the volume of water in the entire system is 2100 ± 400 gal [5] which reduces the concentrations after a year of such running to 46 pCi/mℓ of ^{3}H and 95 pCi/mℓ of ^{7}Be. The saturation ^{3}H concentration would be 820 pCi/mℓ. The ^{7}Be would be removed by the resins used to maintain low conductivity. These resins would trap out 0.75 mCi of ^{7}Be per year and would thus have to be disposed of as radioactive waste.

The maximum concentration of ^{3}H which is permitted to be released to the environment is 1 nCi/mℓ[4] One can see that at 1×10^{12} protons/pulse such concentrations are not approached during a one year running period. At concentrations exceeding 1 nCi/mℓ a closed loop system is mandatory. Another problem is that ^{11}C (20.4 min. halflife) is produced with a cross

Conservatively then, the new target box is within the guideline by about a factor of 8.

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The author appreciates helpful discussions with S.I. Baker and J. Lach.

References:
1. A. Van Ginneken, FN-272
2. Fermilab Radiation Guide, Chapter 12
3. P.J. Gollen, TM-816
4. S.I. Baker, private communication
5. J.T. Lach, private communication

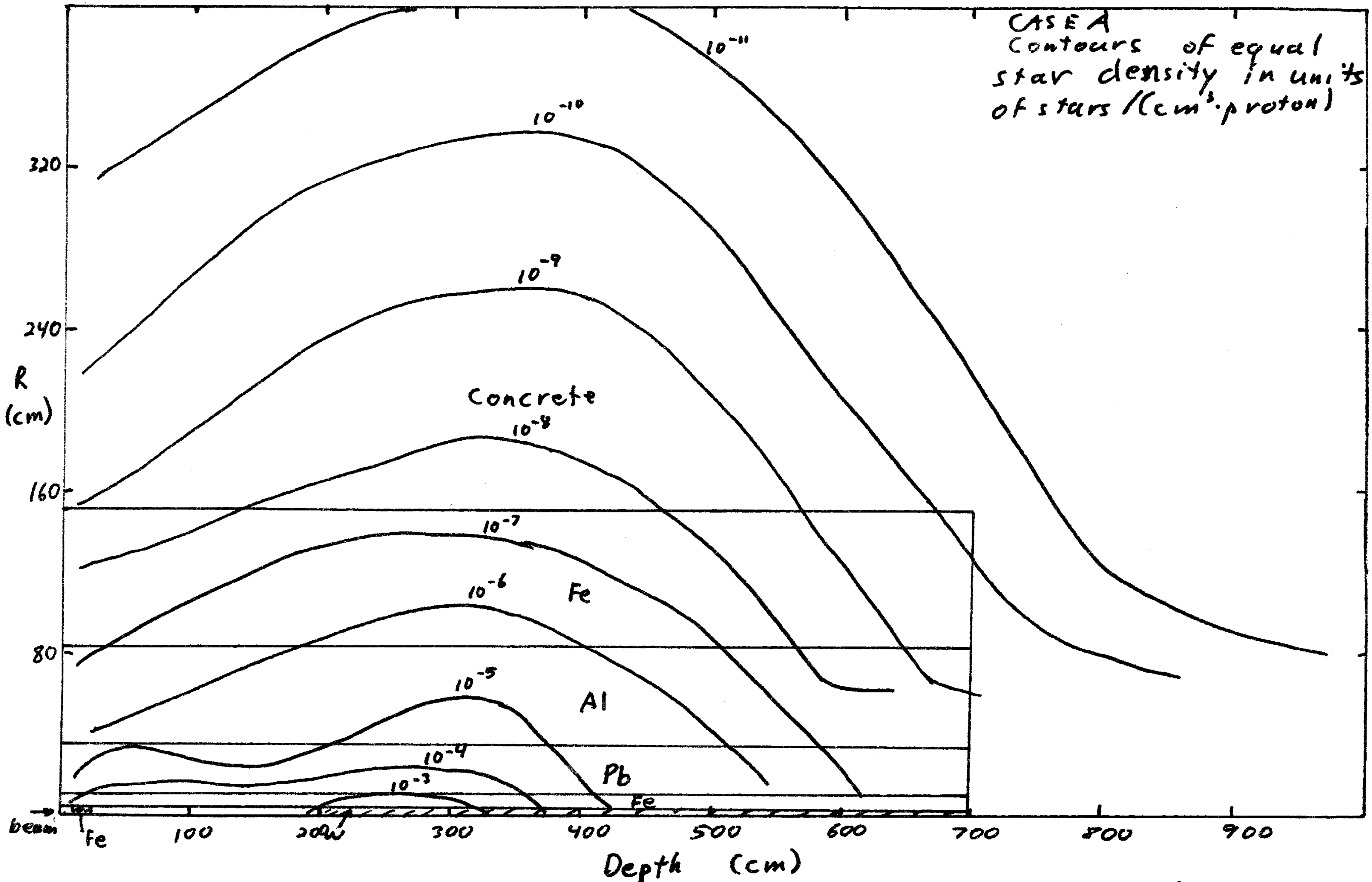

CASE A
Contours of equal star density in units of stars/(cm³·proton)
10^{-11}
10^{-10}
10^{-9}
Concrete
10^{-8}
10^{-7}
Fe
10^{-6}
Al
10^{-5}
Pb
10^{-4}
10^{-3}
Fe
R (cm)
320
240
160
80
beam
Fe
100
200
W
300
400
500
600
700
800
900
Depth (cm)

Figure 1

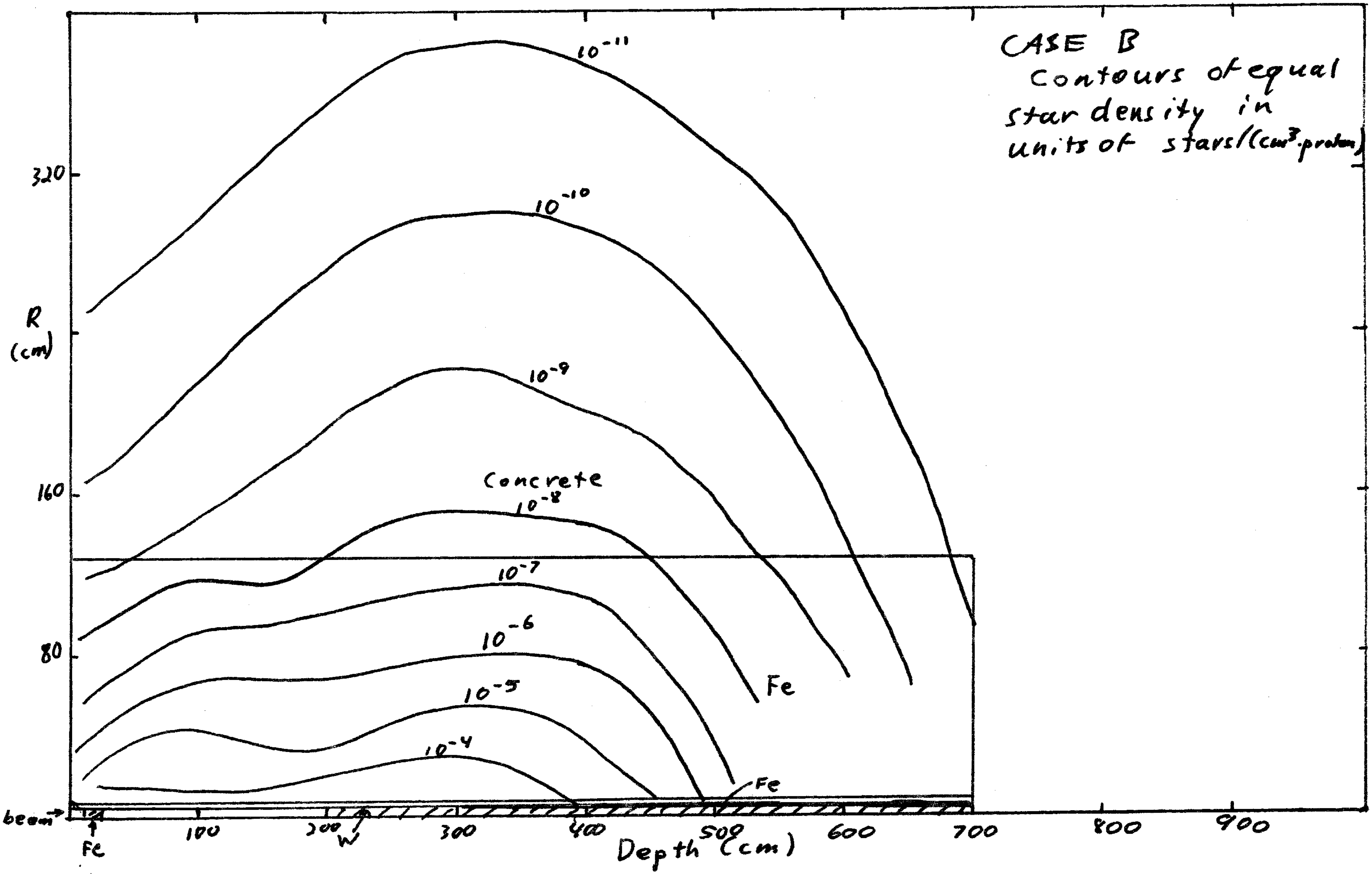
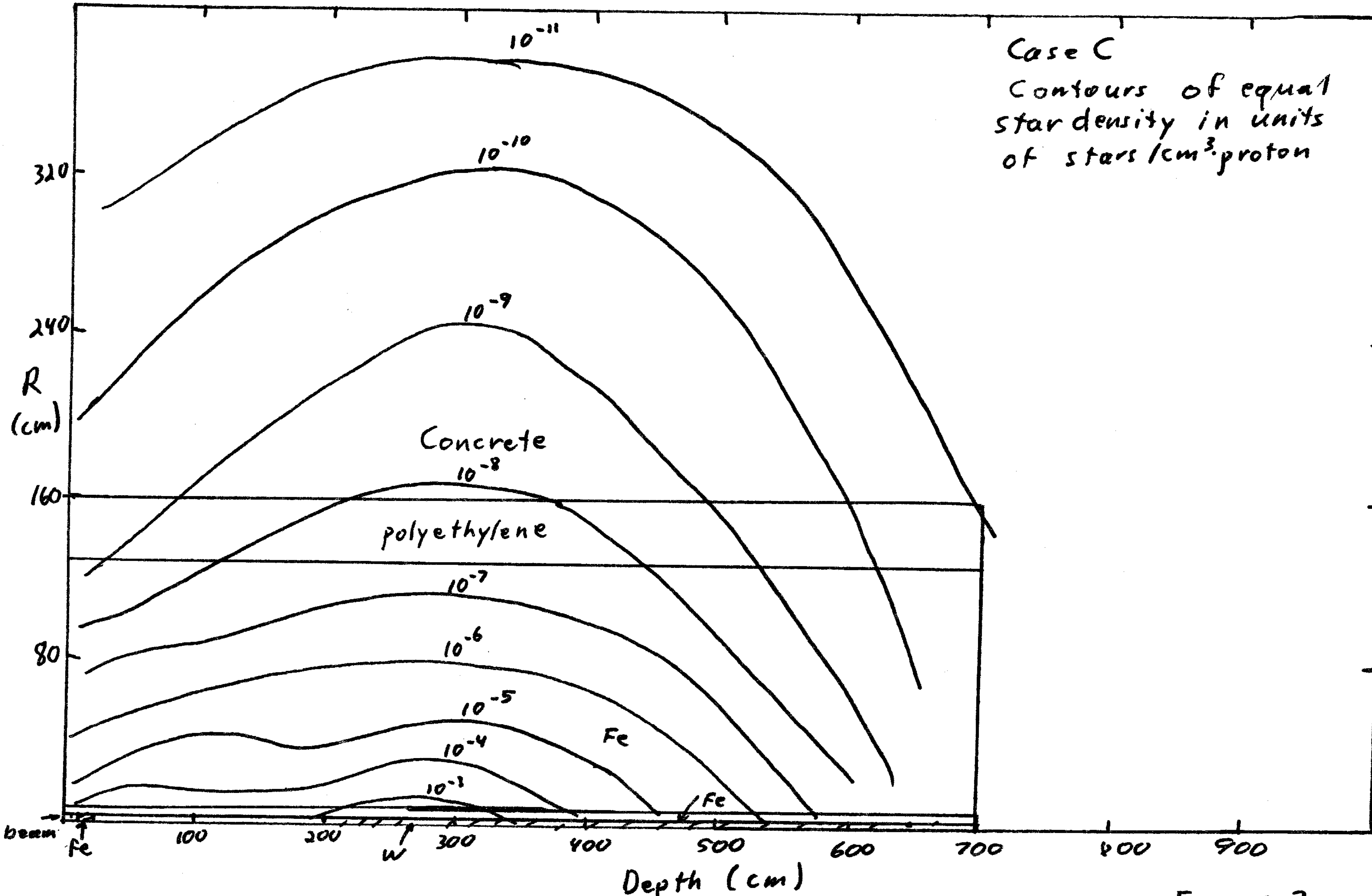

CASE B
Contours of equal star density in units of stars/(cm³·proton)
320
R (cm)
160
80
beam
Fe
100
200
W
300
400
500
600
700
800
900
Depth (cm)
10⁻¹¹
10⁻¹⁰
10⁻⁹
Concrete
10⁻⁸
10⁻⁷
10⁻⁶
10⁻⁵
10⁻⁴
Fe
Fe

Figure 2



Case C
Contours of equal stardensity in units of stars/cm³·proton
10⁻¹¹
10⁻¹⁰
10⁻⁹
Concrete
10⁻⁸
polyethylene
10⁻⁷
10⁻⁶
10⁻⁵
Fe
10⁻⁴
10⁻³
Fe
320
240
R (cm)
160
80
beam
Fe
100
200
W
300
400
500
600
700
800
900
Depth (cm)

Figure 3